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6. AUTHOR(S)

Hemantha W. Wijesekera
Timothy J. Boyd

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OSU
Corvallis, OR 97331

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We have developed and tested a sensor payload section consisting of CTD, optics, ADCP, and microstructure sensors for use with a Bluefin Robotics Odyssey III Autonomous Underwater Vehicle (AUV). We have deployed the AUV, including our payload section, from various platforms in a variety of weather conditions and sea states.

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AUV-Based Measurements of Turbulence in the Oregon Coastal Ocean

Hemantha W. Wijesekera
COAS, 104 OC Admin. Bldg., Oregon State University, Corvallis, OR 97331-5503
Phone: (541) 737-2568 fax: (541) 737-2064, email: hemantha@coas.oregonstate.edu

Timothy J. Boyd
COAS, 104 OC Admin. Bldg., Oregon State University, Corvallis, OR 97331-5503
Phone: (541) 737-4035 fax: (541) 737-2064, email: tboyd@coas.oregonstate.edu

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LONG-TERM GOALS

Our long-term goals are to understand the mechanisms of turbulence and mixing in the coastal ocean environment sufficiently well to be able to incorporate mixing processes in coastal circulation models as sub-grid scale parameterizations. We plan to achieve our long-range objectives by collecting concurrent data sets of microscale, finescale, and mesoscale variables from sensors mounted on an autonomous underwater vehicle.

SPECIFIC OBJECTIVES

The main objective of this study is to demonstrate the feasibility of simultaneously collecting microstructure, hydrographic, and velocity data from an autonomous underwater vehicle (AUV) platform and ancillary data over the Oregon continental shelf.

APPROACH

The approach is to collect data off the coast of Newport, Oregon using an AUV acquired from Bluefin Robotics in combination with a sensor payload section developed at OSU. The proposed test and field surveys were conducted on the spring and summer of 2003.

WORK COMPLETED

We have developed our payload section, which includes sensors capable of measuring hydrography, horizontal currents, turbulent mixing, and bio-optical fields (Figure 1). The majority of sensor packages are rated up to a depth of about 1 km. Details of the sensors are given in Table 1. The payload development, testing and field surveys were conducted in collaboration with Dr. S. Pegau, who is mainly responsible for AUV optics. In our first year of operating the AUV we have conducted several surveys over the Oregon continental shelf (e.g., Figure 2). The objectives of this work were become familiar with AUV operations and navigation, and to collect concurrent measurements of microstructure, horizontal velocity and optical properties. In the second year, we used the AUV to examine mixing and associated bio-optical-physical processes at coastal fronts over the Oregon shelf off Newport.

We have tested the AUV's ability to sample in the upper ocean in a variety of modes: including sawtooth (i.e. "yo-yo") transects, repeated horizontal transects at several depths in a single plane (a "ladder"), and horizontal surveys (i.e. "mowing the lawn"). During this testing we established some baseline characteristics of the AUV as presently configured, and identified areas that need future improvement. For example, when traveling on a straight and level path the AUV is extremely stable, with rms depth fluctuations < 0.05m, rms pitch <1° and rms roll <1°. On the other hand, navigational

accuracy needs improvement from the order 10% of distance traveled at present. An example of small amplitude (~1.5m) sawtooth sampling bracketing a constant depth horizon is shown Figure 3.

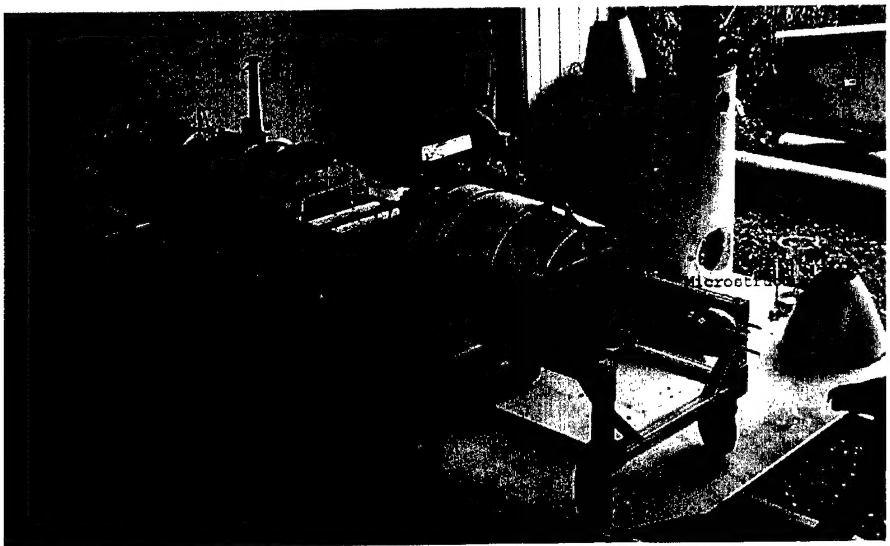

Figure 1. Odyssey III AUV. Showing payloads in front and mid-sections and navigational/control systems and propeller in the tail section.

Figure 2: Cruising on the surface during a calm day (left panel). Retrieving the AUV during a test trial on the R/V Wecoma off the coast of Oregon, March, 2003 (right panel).

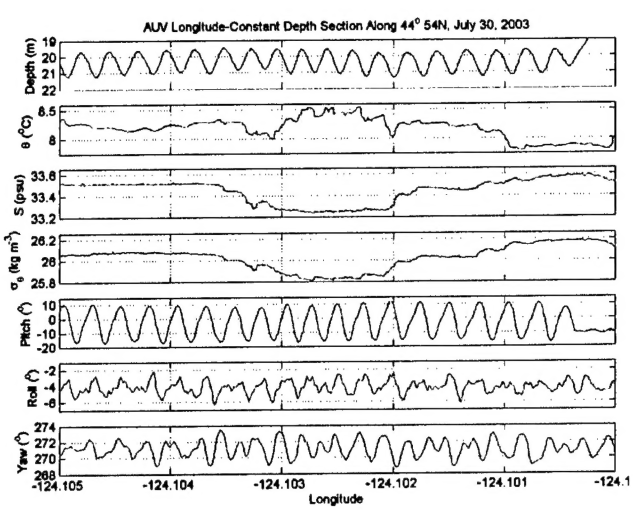

Figure 3. A short (~ 400 m) section of small amplitude sawtooth sampling at around 20m depth, showing (from top to bottom): depth of the AUV, temperature (θ), salinity (S), and density (σ_θ) along the AUV path, followed by AUV pitch, roll, and yaw. Note that the vehicle pitch changes smoothly as the AUV progresses, and that roll and yaw fluctuations are small amplitude.

Table 1: AUV payload and sensor information

Instrument Package	Sensors, Variables	Sampling Rate
Hydrographic	SBE25-CTD; C, T, and P	8 Hz
Velocity	1200 kHz upward looking ADCP; high-resolution horizontal velocity components	15 m depth range, 0.25 m vertical bins
	300 kHz downward looking DVL/ADCP; horizontal velocity components	200 m depth range, 4 m vertical bins
Microstructure	1 Microscale conductivity sensor: C, dC/dx; product: turbulent temperature variance dissipation rate, χ ($^oC^2/s$)	2048 Hz
	2 Shear probes: dU/dy, dU/dz; product: TKE dissipation rate, ε (W/kg)	2048 Hz
	1 Fast response thermistor, FP10: T, dT/dx,	256 Hz
	1 Pressure sensor, P	256 Hz
	Three-axis linear accelerometer: Ax, Ay, Az	256 Hz
	Seapoint Turbidity sensor (880 nm wavelength with 0.05s time constant)	256 Hz
Optical (PI: W. Scott Pegau)	WetLabs AC9+ : 9-channel spectrometer	8 Hz
	7-channel upward looking irradiance sensor	6 Hz
	Backscattering sensor	10 Hz
	ISUS NO_3 sensor	0.5 Hz

RESULTS

We have developed and tested a sensor payload section consisting of CTD, optics, ADCP, and microstructure sensors for use with a Bluefin Robotics Odyssey III Autonomous Underwater Vehicle (AUV). We have deployed the AUV, including our payload section, from various platforms in a variety of weather conditions and sea states. Below we summarize some interesting observations made cross a coastal frontal boundary during a period of relaxation winds.

Yo-Yo Flight: Data shown in Figure 4 were collected while the AUV was moving in a "yo-yo" pattern between 1 and 35 m, and 1 and 20 m depths with a pitch of 10^o. The typical cruising speed of the AUV is about 1.7 m/s. Measurements were made on October 2, 2003. The warm, low-salinity water in the offshore side of the front was from Colombia River plume water, which was moving toward shore as winds changes from weakly upwelling favorable to weakly downwelling favorable (~1-3 m/s). It appears that the plume water converged at the leading edge of the front, which in turn caused subduction. The subduction at the leading edge can be identified from temperature and chlorophyll, and also from the relatively high temperature variance dissipation rate. The leading edge of the front was transformed into a wave-like frontal structure.

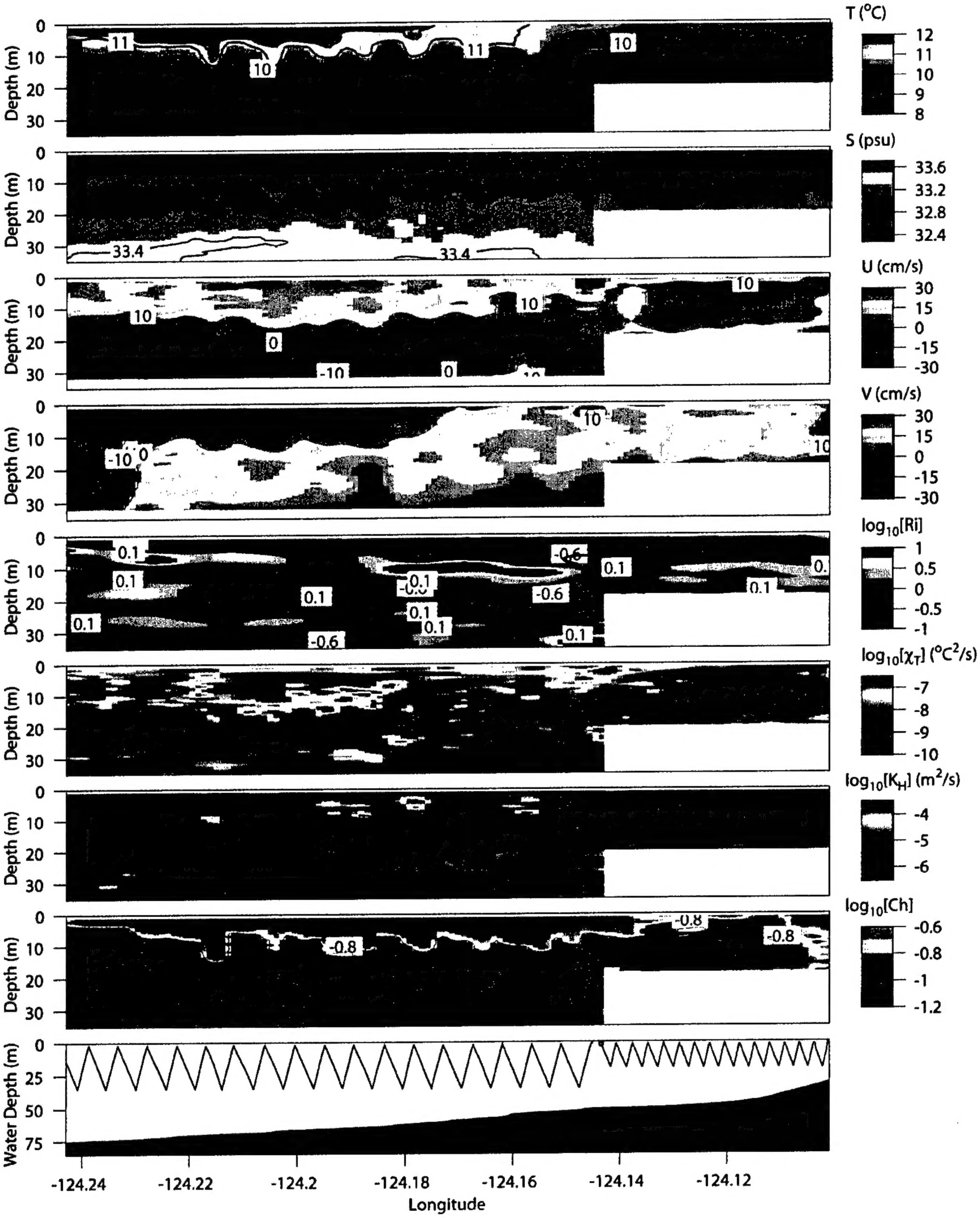

Figure 4. AUV observations off Newport, OR: Longitude – depth (x-z) section along 44° 39' (Newport Hydrographic line), October 2, 2003. Fields of temperature, T (°C), salinity, S (psu), zonal velocity, U (cm/s), meridional velocity, V (cm/s), Richardson Number, Ri, temperature variance dissipation rate, χ_T (°C^2/s), eddy diffusivity, K_H (m^2/s) based on Osborn-Cox formalism, and chlorophyll, Ch (μg/L) derived from AC9+ spectral channels (from Scott Pegau), and "yo-yo" AUV flight pattern and water depth (m). χ_T was derived from conductivity microstructure measurements (for details see Dillon et al., 2003). U and V velocities were from 1200 kHz upward looking ADCP. Ri was based on 1-m vertical and 33 m horizontally averaged total shear squared and buoyancy frequency fields.

Level Flight: The level flight at a depth of 12 m (Figure 5) illustrates frontal wave/mixing patterns and velocity structure in the upper 10 m across the low-salinity front. We noted that Richardson numbers were between 0.1 and 1 and mixing was intense (Figure 4). Some properties of these wave are: wavelength ~ 200 to 700 m; vertical displacements ~ 5 m; propagating toward southeast direction with speed ~0.2 – 0.4 m/s. We obtained similar sets of near surface data at frontal boundaries in June, August, and October along with meteorological measurements.

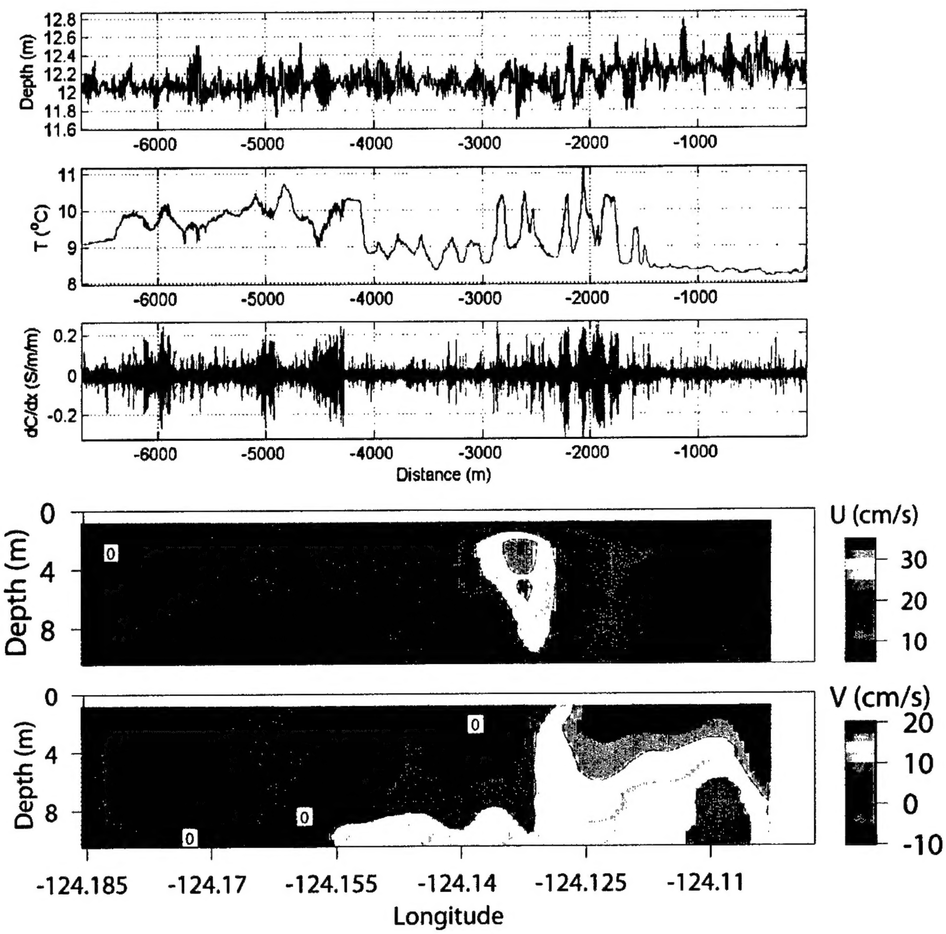

Figure 5. AUV observations off Newport, OR, Oct 2, 2003. Constant level flight at depth 12 m, along Newport Hydrographic line. This level flight was made after completing the "yo-yo" flight shown in Figure 4. The top three panels show depth (m), temperature (°C) and micro-scale conductivity gradient (S/m/m) from the MicroSoar microstructure sensing package. Bottom two panels show upper 10 m U and V velocities (cm/s) from the upward looking 1200 kHz ADCP. Highly energetic and dissipative wave packets moved toward east at the leading edge of low-salinity front. There is significant structure in surface currents and their vertical shears are in the upper 10 m.

IMPACT/APPLICATIONS

We have demonstrated that AUV is a useful robust platform for sampling near surface velocity, hydrography, turbulence, and optical fields for a given region of the coastal ocean.

TRANSITIONS

None

RELATED PROJECTS

ONR sponsored AUV-based observations off the coast of Oregon; a collaborative project with Scott Pegau, Andrew Dale, John Barth, and Timothy Cowles.

REFERENCES

None

PUBLICATIONS

Wijesekera, H. W., T. J. Boyd, W. S. Pegau, I. MacCallum, G. H. May, and C. Waluk, 2003: Measurements of mixing off the coast of Oregon using autonomous underwater vehicle, Eos Trans. AGU, 84(52), Ocean Sci. Meet Suppl. Abstract OS42M-04.

PATENTS

None